

**TABLE OF CONTENTS**

<b>CHAPTER</b>	<b>TITLE</b>	<b>PAGE</b>
	<b>DECLARATION OF THESIS</b>	<b>i</b>
	<b>SUPERVISOR'S DECLARATION</b>	<b>ii</b>
	<b>TITLE PAGE</b>	<b>iii</b>
	<b>DECLARATION OF ORIGINALITY</b>	<b>iv</b>
	<b>ACKNOWLEDGEMENT</b>	<b>v</b>
	<b>ABSTRACT</b>	<b>vi</b>
	<b>ABSTRAK</b>	<b>vii</b>
	<b>TABLE OF CONTENTS</b>	<b>viii</b>
	<b>LIST OF TABLES</b>	<b>x</b>
	<b>LIST OF FIGURES</b>	<b>xi</b>
	<b>LIST OF ABBREVIATIONS</b>	<b>xii</b>
	<b>LIST OF SYMBOLS</b>	<b>xiii</b>
	<b>LIST OF APPENDICES</b>	<b>xv</b>
<b>1</b>	<b>INTRODUCTION</b>	<b>1</b>
	1.1 Problem Statement	4
	1.2 Objectives of Research	5
	1.3 Scope of Research	5
	1.4 Significance	6
	1.5 Structure of the Study	6

<b>2</b>	<b>LITERATURE REVIEW AND THEORETICAL BACKGROUND</b>	<b>8</b>
2.1	Introduction	8
2.1.1	Structural Dynamics	8
2.1.2	Inverse Process of Damage Detection	9
2.2	Literature Review	10
2.2.1	Natural Frequencies	10
2.2.2	Mode Shapes	12
2.2.3	Artificial Neural Network (ANN)	13
2.3	Theoretical Background	18
2.3.1	ANN Architecture	18
2.3.1.1	The Multilayer Perceptron (MLP)	18
2.3.1.2	Different Activation Functions	20
2.3.1.3	Hidden Layers	21
2.3.1.4	Overfitting and Early Stopping	21
2.3.2	Input and Output Parameter	22
2.3.3	Backpropagation Training Algorithm	24
2.3.3.1	Gradient Descent Backpropagation Algorithm	24
2.3.3.2	Gradient Descent with Momentum and Adaptive Learning Rate Algorithm	25
2.3.3.3	Scaled Conjugate Gradient Algorithm	26
2.3.3.4	Resilient Backpropagation Algorithm	27
2.3.3.5	Levenberg Marquardt Algorithm	28
2.3.4	Advantages of Levenberg Marquardt Training Algorithm	29
2.3.5	Advantages of ANN Application	30
<b>3</b>	<b>METHODOLOGY</b>	<b>31</b>
3.1	Literature Review and Finite Element Modelling	32
3.2	Development of ANN Model	38
3.2.1	Assembling Data	38
3.2.2	ANN Architecture	39

3.2.3	ANN Training and Validating	40
3.3	Damage Detection with Test Data	41
3.4	Analysis	42
3.5	Conclusion and Recommendation	44
<b>4</b>	<b>RESULTS AND ANALYSIS</b>	<b>45</b>
4.1	Introduction	45
4.2	Damage Detection using ANN	45
4.3	Sensitivity Study on the Effect of Different Training Algorithm and Input Combinations to ANN's Training	49
4.4	Parametric Study on the Effect of Different Input Variable to ANN (Different Training Algorithm) Prediction Performance	52
4.5	Summary	53
<b>5</b>	<b>CONCLUSION AND RECOMMENDATION</b>	<b>55</b>
	<b>REFERENCES</b>	<b>57</b>
	<b>APPENDICES A - B</b>	<b>61 - 74</b>

## LIST OF TABLES

TABLE	TITLE	PAGE
3.1	Natural frequencies for undamaged state	34
3.2 (a)	$E$ values for damage and undamaged state in slab model	35
3.2 (b)	Natural frequencies of the slab in different damage states (Hz)	35
3.3 (a)	$E$ values for damage and undamaged state in frame model	36
3.3 (b)	Natural frequencies of the frame in different damage states (Hz)	36
3.4 (a-b)	$E$ values for damage and undamaged state in slab and frame model	42
3.5	Case study with different parameters	43
4.1 (a-b)	Effect of different training algorithm and input combinations to ANN's training time	49
4.2 (a-b)	Effect of different training algorithm and input combinations to ANN's training performance	51
4.3 (a-b)	Effect of different training algorithm and input combinations to ANN's testing performance	52

## LIST OF FIGURES

FIGURE	TITLE	PAGE
2.1	ANN architecture	19
2.2	Neuron function	19
2.3	Tansig and Purelin transfer function in neuron (Hagan et al., 1995)	20
2.4	Logsig transfer function in neuron (Hagan et al., 1995)	20
3.1	Flow chart of research	31
3.2	Slab model meshing in plan view (Bakhary, 2008)	32
3.3	Slab model in plan view (Bakhary, 2008)	33
3.4	Finite element modelling of slab (Bakhary, 2008)	33
3.5	Finite element meshing of frame (Bakhary, 2008)	34
3.6 (a-c)	Mode deflection in different damage state for slab model	36
3.7 (a-c)	First 3 mode deflection in different damage state for frame model	37
3.8	Tansig and Purelin transfer function in neurons (Hagan et al., 1995)	39
3.9	Transfer functions in hidden layer and output layer neurons	40
4.1 (a-e)	Slab single damage detection with different ANNs	46
4.2 (a-e)	Slab multiple damage detection with different ANNs	47
4.3 (a-e)	Frame single damage detection with different ANNs	48
4.4 (a-e)	Frame multiple damage detection with different ANNs	48

## LIST OF ABBREVIATIONS

ANN	-	Artificial Neural Network
COMAC	-	Coordinate Modal Assurance Criterion (COMAC)
FEM	-	Finite Element Model
FRF	-	Frequencies Respond Functions
Logsig	-	Log-Sigmoid
MAC	-	Modal Assurance Criterion
MLP	-	Multi-Layer Perceptron
MSE	-	Min Square Error
Purelin	-	Linear
SHM	-	Structural Health Management
SOM	-	Self Organising Maps
SRF	-	Stiffness Reduction Factor
Tansig	-	Tangent-Sigmoid

## LIST OF SYMBOLS

$[A]$	-	Damaged mode shape
$[A']$	-	Normalised mode shape
$A_k$	-	Hessian matrix
$[B]$	-	Original undamaged mode shape
$\beta_k$	-	Update value for Scaled Conjugate Gradient algorithm
$[C]$	-	Vector of damping
$\Delta X$	-	Weight change for Resilient Backpropagation algorithm
$dX_{prev}$	-	Previous change to the weight or bias
$\frac{dperf}{dx}$	-	Gradient in transfer function
$\mathbf{e}$	-	Network error vector
$E$	-	Young Modulus
$\{f(t)\}$	-	Vector of input forces
$gX$	-	Gradient in Resilient Backpropagation algorithm
$\mathbf{J}$	-	Jacobian matrix that contains the first derivatives
$[K]$	-	Stiffness matrices
$\lambda_{jk}$	-	$j^{th}$ Mode frequency at $k^{th}$ cases
$lr$	-	Learning rate
$[M]$	-	Vector of mass
$mc$	-	Momentum and learning rate adjustment
$\{\phi_i\}$	-	$i^{th}$ Mode shape
$\phi_{jk}$	-	$j^{th}$ normalised mode displacement at $k^{th}$ cases
$P$	-	Mass Density
$(P_0)$	-	Steepest descent direction
$p_R$	-	$R^{th}$ Input for neuron's transfer function

$SRF_{nk}$	-	SRF for segment at $k^{th}$ cases
$\nu$	-	Poisson Ratio
$\omega_i$	-	$i^{th}$ Modal circular frequency
$w_{1,R}$	-	$R^{th}$ Weight in transfer function
$\{\ddot{X}\}$	-	Vector of acceleration
$\{\dot{X}\}$	-	Vector of velocity
$\{X(t)\}$	-	Vector of displacement



**LIST OF APPENDICES**

<b>APPENDIX</b>	<b>TITLE</b>	<b>PAGE</b>
A	Training performance and training time for slab's case studies	61-67
B	Training performance and training time for frame's case studies	68-74